PIPEOTECH

Stability and tightness of damaged flange joints with DeltaV-Seal Gaskets

Imperfections on flange faces happen. With more and more companies adopting low emissions business practices, can damaged flange surfaces provide a suitable seal to meet environmental compliance?

Contents

1. Introduction

Imperfections on flange faces happen. With regular maintenance and removing old, stuck-on gasket/debris, flanges with scratches, pits, dents, and gouges are a common occurrence in many process plants. With more and more companies adopting low emissions business practices, can damaged flange surfaces provide a suitable seal to meet environmental compliance?

In the fluid sealing world, it is a well-known fact the flange surface quality is directly related to sealing capability and sealing capability is directly related to environmental compliance. As a major portion of all known flange gasket failures are installation related, installers must take extra care when sealing damaged flange faces. Acknowledging the importance of proper gasket installation, Pipeotech is recommending all installers to be qualified according to EN 1591-4 before installing DeltaV-Seal gaskets.

To investigate DeltaV-Seal's robustness when installing on damaged flanges, Pipeotech has derived stability and tightness performance of DeltaV-Seal gaskets by calculations in accordance with EN 1591-1 supported with thorough laboratory testing of gasketed bolted flange joints (BFJ) consisting of one flange with damage and one undamaged flange.

The purpose of the calculations is to ensure structural integrity and control of leak tightness of the gasketed BFJ using the gasket parameters based on definitions and test methods specified in EN 13555. The gasket parameters for DeltaV-Seal gaskets have been obtained by extensive laboratory testing programs reported elsewhere and available upon request.

The results of the calculations have been correlated with actual leakage testing under internal pressure by helium (5 barg) and water (77 barg).

Flange damage assessments have been performed following the guidelines in ASME PCC-1, Appendix D hereunder following Table D-2M and Figure D-4 Flange Surface Damage Assessment: Scratches and Gouges.

2. Stability/tightness calculations (EN 1591-1)

The EN 1591-1 standard defines a calculation method for bolted, gasketed, circular flange joints. Its purpose is to ensure structural integrity and control of leak tightness. It uses parameters based on definitions and test methods specified in EN 13555.

Selected flange size and pressure class, load cases (LC) and input data to the calculations and laboratory leakage testing are described in subsequent paragraphs.

2.1 Selected load cases (LC)

Pipeotech selected standard carbon steel ASTM A105N ASME 2" #300 flanges for these investigations for which DeltaV-Seal S235 2" #300 gaskets in accordance with ASME B16.20 are suitable.

The following two operational LC were selected:

- as medium at 5 barg pressure; operation temperature 20°C
- Liquid water as medium at 77 barg pressure; operation temperature 20°C

Input data for the EN 1591-1 calculations are described in the following paragraph.

2.2 EN 1591-1 calculations

2.2.1 Input data

The EN 1591-1 calculation formulas are available commercially in certified software packages containing all required algorithms which makes the application of the standard reliable, reproducible, and practical. All calculations are documented in a report for each LC which can be made available upon request.

The following input data has been used for the two selected LC:

- Blind flange material: ASTM A105N
- Bolting: BS EN ISO 898-1 Property Class 8.8: 8 off M16 bolts
- Gasket: DeltaV-Seal S235
- Gaseous helium leakage rate (L): 1e-6 mg/m/s; this leakage rate has been selected to underpin the detectability of the leakages in the laboratory testing, see subsequent paragraphs
- Leakage pressure during EN 13555 testing (P_G): 40 barg
- Required minimum design seating stress for tightness class L Assembly ($Q_{min(L)}$): 195 MPa
- Gasket seating stress before unloading (Q_A): 200-500 MPa
- Coefficient of friction between gasket and flange contact facing: 0.3
- Thermal expansion coefficient of gasket: 11.5e-6/K
- External forces/moments: none, see subsequent paragraphs

2.2.2 Results of calculations

The main results of the calculations relevant to the laboratory testing conditions are shown in Table 1.
The calculations show the same nominal forces and moments for both load cases (5 barg helium and 78 barg water). However, the 2nd load case gives higher utilization of the flanges but still with acceptable load ratios.

Nominal forces/nominal moments:			
Nominal bolt torque	Minimum value for tightness (required)	$M_{t,nom}$	49.68 Nm
Nominal bolt torque	Maximum value of load ratio (allowable)	$M_{t,nom}$	88.4 Nm
Nominal bolt force	Minimum value for tightness (required)	$F_{B0\ nom}$	219357 N
Nominal bolt force	Maximum value of load ratio (allowable)	$F_{B0\ nom}$	390290 N

Table 1

The calculations predict the range of bolt torque-up (49.68 – 88.4 Nm) required to provide an ASME 2” #300 BFJ gasketed with DeltaV-Seal S235 with sufficient mechanical stability and with a leak rate less than 1e-6 mg/m/s under the stated conditions.

The main intention of this paper is two-fold:

- To correlate the calculated torque-up values with the physical BFJ torque-up values used during the laboratory testing
- To demonstrate DeltaV-Seal gasket’s robustness against flange surface damages under working conditions

The results also show that selecting the gasket surface pressure (Q_A) for this gasket (and any other gasket) is by no means an unambiguous process. In general, the higher the surface pressure, the lower the resulting leak tightness class will be. It is therefore normally purposeful to select as high as possible surface pressure to safely comply with the required leak tightness class, as long as the permissible tensions of all components are complied with.

According to EN 1591-1, only the minimum required bolt-up force is relevant for complying with the minimum surface pressure in the subsequent states of the BFJ. Higher bolt-up forces that would result in the allowable stresses for the calculation being exceeded would likely produce local plasticizing that, however, are limited in themselves as these are secondary stresses (plastic limit stress).

3. Laboratory testing

3.1 Scope of testing

Leakage testing was performed on BFJ samples with the following damages introduced on one of the two flange halves:

- 0.3 mm damage on the Raised Face (RF) area of the flange
- 0.2 mm damage on the RF area of the flange
- 0.1 mm damage on the RF area of the flange

The three blind flanges with the introduced damage stretching across the complete RF diameter are shown in Figure 1 below.

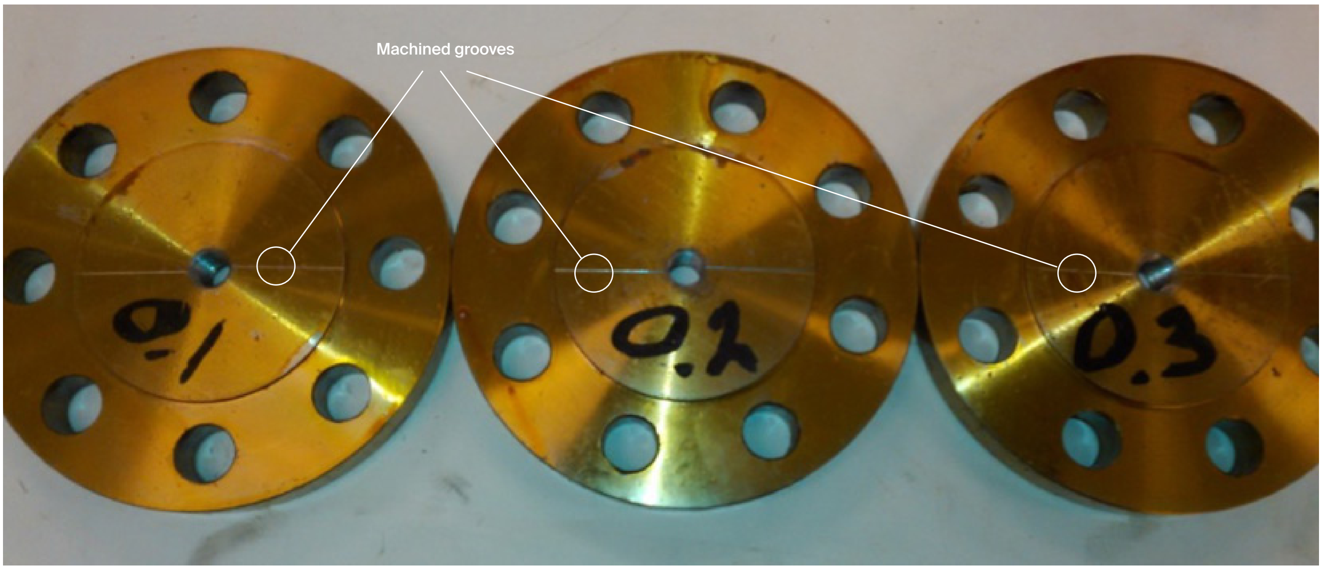


Figure 1

3.2 Flange damages/imperfections

3.2.1 ASME PCC-1:2019 Appendix D, Table D-2M, Figure D-4

In accordance with Table D-2M Allowable Defect Depth vs. Width Across Face the allowable defect depth is correlated to the width (w) of the seating surface of the gasket (area where the gasket seats both initially and after assembly). Due to the unique design of DeltaV-Seal gaskets sealing on local contact points, it is not trivial how to define the seating surface in the context of defining allowable defect depth) in contrast to most of the other standard gasket technologies.

The referred table states that if the projected radial distance across the seating surface (r_d) is larger than ½ of the gasket seating area width (w), then no flange surface defect is allowed for hard-faced gaskets whereas for soft-faced gaskets like spiral wound gaskets (SWG) a depth of 130 microns is allowed. Likewise, if the projected radial distance across the seating surface (r_d) is larger than ¾ of the gasket seating area width (w), then no flange surface defect is allowed for soft-faced gaskets.

Pipeotech has considered these aspects during the design of synthetic defects and selected the 'Scratches and Gouges' option in the standard for the flange surface damage assessments, refer to Figure D-4 of Appendix D. To ensure conservatism in the investigation it was further decided to extend the width of the defects across the complete width of the RF of the flanges when assessing the ability of DeltaV-Seal gaskets to tolerate imperfections.

3.2.2 Machining of flange damage/imperfections

The machining procedure for preparing the flange imperfections/damages is provided in Appendix 1.

3.3 Testing procedures

The testing procedures are provided in Appendix 2.

3.4 Leakage detection and retightening of bolts

Fundamental to any leakage investigation, whether in the laboratory or on a site process plant, is the understanding of leakage detection and the detectability of the selected leakage testing method. This is especially important in cases where theoretical tightness calculations are correlated with practical leakage measurements (as in the current investigation). For this purpose, the well-known EN 1779 standard has been applied. This standard describes criteria for the selection of the most suitable method and technique for the assessment of leak tightness by indication or measurement of a gas leakage.

In accordance with Table A.2 – Specific features of leak testing methods – Pressure change method, under the principle of the pressurized object being completely submerged in the test liquid and where the leakages are shown by bubble stream formation, the minimum detectable leakage is stated to be 1e-4 Pa*m^3/s. This volume flow rate translates to a mass flow rate of 3.5e-6 mg/m/s for a 2” #300 DeltaV-Seal gasket as applied in this investigation.

Hence, if no leakage was detected in the current testing, the standard states that the actual leakage rate was less than 3.5e-6 mg/m/s. All test steps were performed by retightening the stud bolts until the test assembly was tight and no leakage and pressure drop were detected during the test duration of five minutes.

4. Results of leakage measurements

The results of the leakage measurements for the three imperfection cases are summarized in Table 2.

Torque step No.	Torque (Nm)	Helium 5 barg			Water 77 barg		
		0.1 mm	0.2 mm	0.3 mm	0.1 mm	0.2 mm	0.3 mm
1	54	No leakage detected	No leakage detected	Leakage	No leakage detected	No leakage detected	Not tested*
2	81			Leakage			Not tested*
3	95			Leakage			Not tested*
4	108			No leakage detected			No leakage detected
5	122						
6	135						
7	149						

Table 2

**: The BFJ with 0.3 mm imperfection/damage was only tested and the leakage monitored at a bolt torque of 108 Nm since this torque level was required for the previous 5 barg helium test.*

The test results show the following:

- A torque of 54 Nm (1st torque step) was sufficient to obtain a leakage rate of <3.5e-6 mg/m/s in a 2” #300 BFJ gasketed with DeltaV-Seal and with a flange surface containing a maximum 0.2 mm deep/0.3464 mm opening width gouge extending across the complete RF diameter at internal pressures up to a maximum of 77 barg.
- A torque of 108 Nm was sufficient to obtain a leakage rate of <3.5e-6 mg/m/s in a 2” #300 BFJ gasketed with DeltaV-Seal and with a flange surface containing a maximum 0.3 mm deep/0.3464 mm opening width gouge extending across the complete RF diameter at internal pressures up to a maximum of 77 barg.

Based on the ASME PCC-1 Appendix D guidelines as described under Section 3.2.1, these results strongly indicate a great robustness of DeltaV-Seal gaskets for tolerating flange imperfections. This is where the referred guidelines do not allow any flange damage (width/depth) at all, DeltaV-Seal is able to seal against a flange surface with an 0.2 mm deep/0.35 mm opening width imperfection/gouge extending across the complete width of the flange RF under full BFJ mechanical stability as shown by the applied torques and further discussed in Section 5.

Photographic documentation during the testing is provided in Appendix 3.

5. Discussion

Neither the ASME PCC-1 guidelines, nor the EN 1591-1 standard make any attempt to correlate allowable flange damage to actual leakage rates. Hence, the degree of conservatism in the PCC-1 guidelines was of interest for Pipeotech to investigate especially considering the unique gasket design of DeltaV-Seal gaskets. For example, in ASME PCC-1, Appendix O, Assembly bolts stress determination the given provisions consider that the component conditions are within acceptable limits without any reference to leakage rates.

As mentioned in previous sections of this paper, the PCC-1 Appendix D guidelines are based on the radial width (w) of the gasket's seating surface across the adjoining flange face, either flat face (FF) or raised face (RF). Most, if not all, of the existing gasket technologies have their seating widths specified in the common gasket standards, i.e., ASME B16.20 and the EN 1514 series of standards and hence the PCC-1 guidelines are conveniently applied to these gaskets.

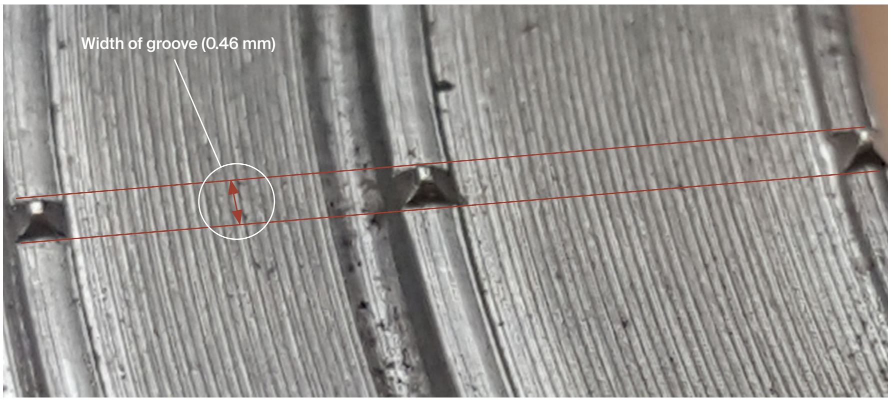
However, the unique DeltaV-Seal design with a certain number, depending on size and pressure class, local and triangular-shaped sealing/contact points, does not ideally lend itself to the same approach since the radial width cannot be defined in the same way as other gasket technologies. For example, where a standard EN 1514-2 DN40 PN40 SW gasket has a width of the rectangular-shaped sealing element of 6 mm, the corresponding DeltaV-Seal has in principle a total sealing width equal to zero at assembly but increasing to around 0.6 mm during a normal bolt-up sequence.

Thus, applying Table D-2M would strictly mean that any flange damage/imperfection with a projected radial distance across the seating surface (r_d) larger than w/2 = 0.6/2 = 0.3 mm would not be allowed irrespective of the depth of the damage/imperfection.

As shown in Table 1 the calculations predict a min/max = required/allowable bolt torque-up values of 50/88 Nm for the BFJ applied in the leakage measurements. The results of the leakage measurements (Table 2) show that torque step No.1 (54 Nm) was sufficient for obtaining the predicted tightness class even for a 'damaged' flange surface with a 0.2 mm deep gouge extending across the complete RF of the flange up to a pressure of 77 barg. For a 0.3 mm deep damage the required torque was shown to be 108 Nm which is exceeding the allowable for the load ratios and would thus not be an acceptable damage.

In summary, the results presented in this paper show that DeltaV-Seal can obtain a tightness class of $L_{0.000001}$ against a flange damage/imperfection extending across the complete width of a flange RF and with a depth of up to 0.2 mm in a BFJ mechanically stable as proven by EN 1591-1 calculations. Hence, the ASME PCC-1 guidelines in terms of allowable flange damage are clearly much too conservative for application to DeltaV-Seal gaskets.

An example of the resulting DeltaV-Seal surface appearance from the interaction with one of the flange surfaces (0.2 mm defect/imperfection depth) used in this investigation is shown in Figure 2.



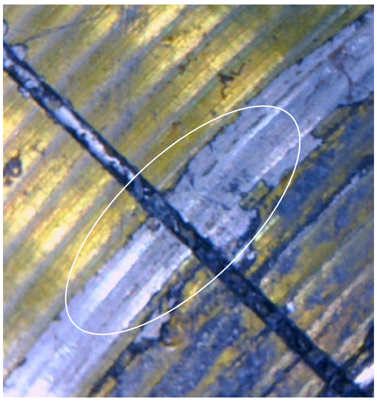


Figure 2

Figure 3

The figure shows that there had been an interaction between the DeltaV-Seal's three sealing points and the bottom of the machined flange groove causing a leakage rate <3.5e-6 mg/m/s (torque step No. 4/108 Nm torque/5 barg helium).

Figure 3 shows the flange surface appearance after test: the machined grooves are clearly visible indicating that the DeltaV-Seal seal ridges are not causing any damage to the flange surface.

6. Summary/conclusions

This paper describes experimental leakage measurements on BFJ's gasketed with DeltaV-Seal and supporting mechanical stability and tightness calculations. The tested joints contained flange surfaces with machined grooves simulating flange surface imperfections/damages occurring on real flanges.

This investigation, applying DeltaV-Seal S235 gaskets, is part of Pipeotech's current technology development program which includes other metallic materials such as stainless steels, Ni-Cr-Fe alloys, and light metals.

Even though Pipeotech recommends avoiding flange surface damage in the gasket installation instructions, the results of this investigation clearly demonstrate DeltaV-Seal's ability to tolerate flange surface imperfections. Such gasket performance is considered to strongly support low-risk and cost-efficient gasket installation works during brownfield, LDAR and other piping/process plant maintenance projects.

The results of the investigation also show that the DeltaV-Seal ridges do not cause any damage to the flange surfaces even at very high assembly torques.

7. References

The following references have been applied in this investigation:

- ASME PCC-1: 2019; Guidelines for Pressure Boundary Bolted Flange Joint Assembly
- EN 1779: 1999+A1; Non-destructive testing, Leak testing, Criteria for method and technique selection
- EN 1591-1: Flanges and their joints, Design rules for gasketed circular flange connections, Part 1: Calculation

Appendix 1 – Machining procedure for flange damage

The following machining procedure was followed for the three blind flanges:

1. All flanges were chucked with 30 Newton in a manual lathe.
2. A 60° thread cutting tool with a radius of 0.1 mm was used for machining the imperfection.
3. A contact point was set between the tool and RF area of the blind flange.
4. Cutting depth of 0.1 mm was set on the top slider. Then the vertical slider was driven from the largest diameter towards the centre hole of the flange.
5. The chuck was turned 180° and the vertical slider was driven from the largest diameter towards the centre hole of the flange.
6. Above operations were repeated for two more blind flanges, but with notch depth of 0.2 mm and 0.3 mm respectively.

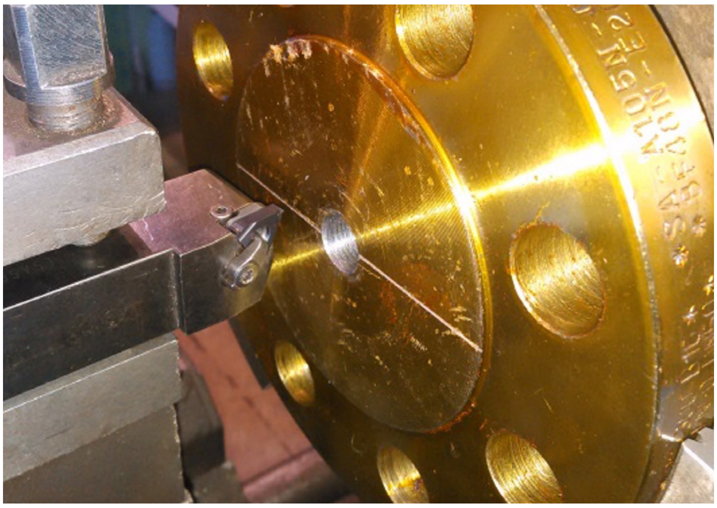


Figure 4

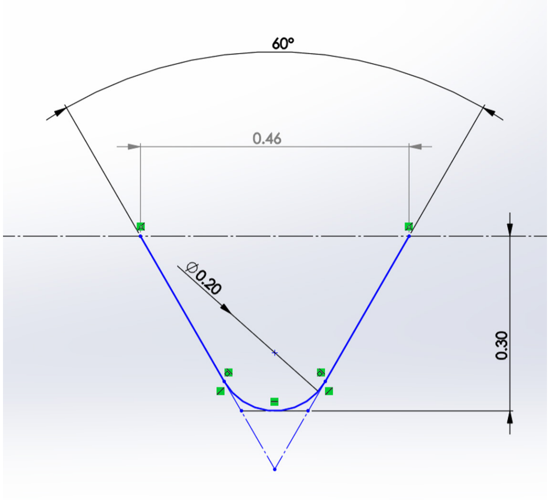


Figure 5

Figure 4 shows machining of the notch/flange imperfection to be used for leakage testing.

The resulting machined groove cross section is shown in Figure 5 (Case 3: groove depth = 0.3 mm/ groove width = 0.46 mm). Bottom of groove with a 0.1 mm radius.

The three applied groove cases were as follows:

Case	Groove depth (mm)	Groove width (mm)
1	0.1	0.23
2	0.2	0.35
3	0.3	0.46

Table 3

Appendix 2 – Testing procedures

Gaseous helium testing

The following testing procedure was followed:

1. The coupling assembly was connected to the helium gas bottle.
2. 5 bar helium was applied.
3. The test assembly was completely submerged in water.
4. The BFJ was observed for any leakage over a period of minimum 5 minutes:
    - If any leakage occurred: the helium tank was closed, and the pressure bled off before re-tightening the assembly in accordance with Table 4 (torque table for stud bolts).
    - This was repeated in steps until no leakage could be detected.

Step No.	Torque (Nm)
1	54
2	81
3	95
4	108
5	122
6	135
7	149

Table 4 - Torque table for stud bolts

5. The helium gas valve was closed, and the pressure bled off.
6. The BFJ was disconnected, and next test started.

Figure 6 – Assembled test sample for gaseous helium testing (One flange with groove and one smooth flange)

The following three tests were carried out with 5 barg helium:

- Case 1: one flange with a 0.1 mm deep groove
- Case 2: one flange with a 0.2 mm deep groove
- Case 3: one flange with a 0.3 mm deep groove

Liquid water testing

The following testing procedure was followed:

1. The coupling assembly was filled with water and purged for air.
2. The test assembly was filled with water.
3. The hose was filled with water.
4. An Enerpack pump was connected to the hose and onto the CEJN coupling on the test assembly flange A (left flange) containing the machined imperfections.
5. While pumping water, the assembly was vented through the valve in blind flange B (right flange).
6. The valve at flange B was kept as the highest point to ensure completely purged assembly for air before the valve was closed.
7. The assembly was then pressurized to 1.5 times the design pressure for the selected ASTM A105N ASME B16.5 2” #300 flanges, i.e., 76.7 bar. This test pressure was attained within a period of not less than 15 seconds and not more than 60 seconds.
8. The pressure was then retained for a minimum period of 5 minutes.
9. The pressure was finally bled off before the test equipment was disconnected.

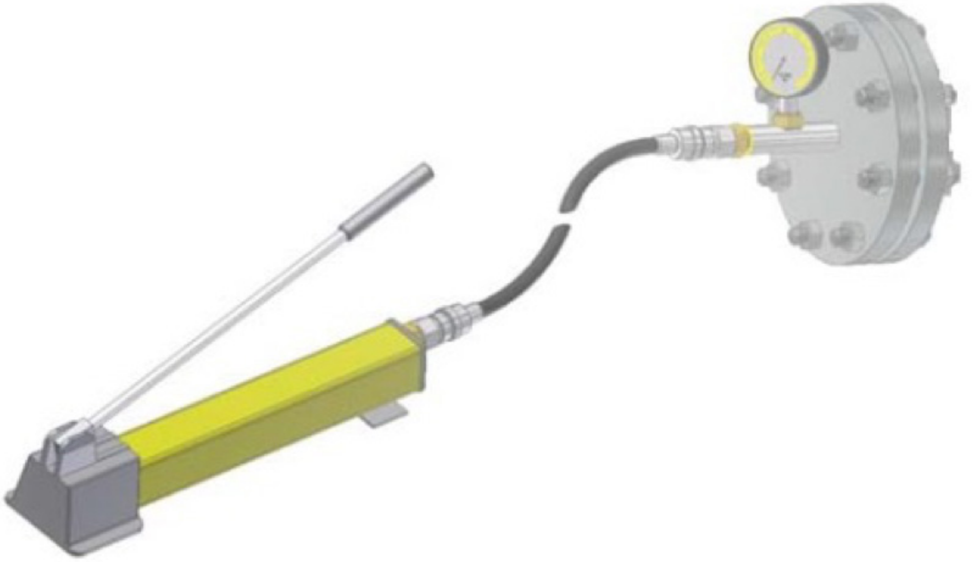


Figure 7 – Test set-up for pressurized water testing (flange A to the left/flange B to the right)

The following three tests were carried out with water:

- Case 1: one flange with a 0.1 mm deep groove
- Case 2: one flange with a 0.2 mm deep groove
- Case 3: one flange with a 0.3 mm deep groove

Appendix 3 – Photographic documentation during leakage testing

Pictures from testing of DeltaV-Seal with use of 0,1 mm damage

Figure 8. Helium test – 5 barg

Figure 9. Helium test – 5 barg

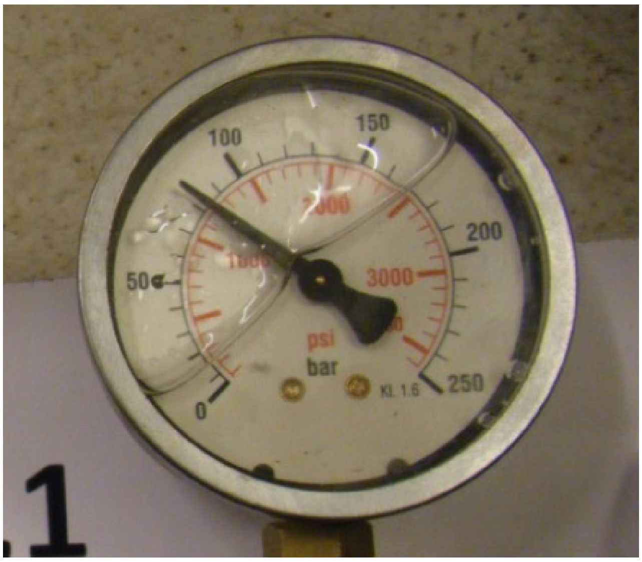


Figure 10. Water testing – 78 barg

Pictures from tes ting of DeltaV-Seal with use of 0,2 mm damage

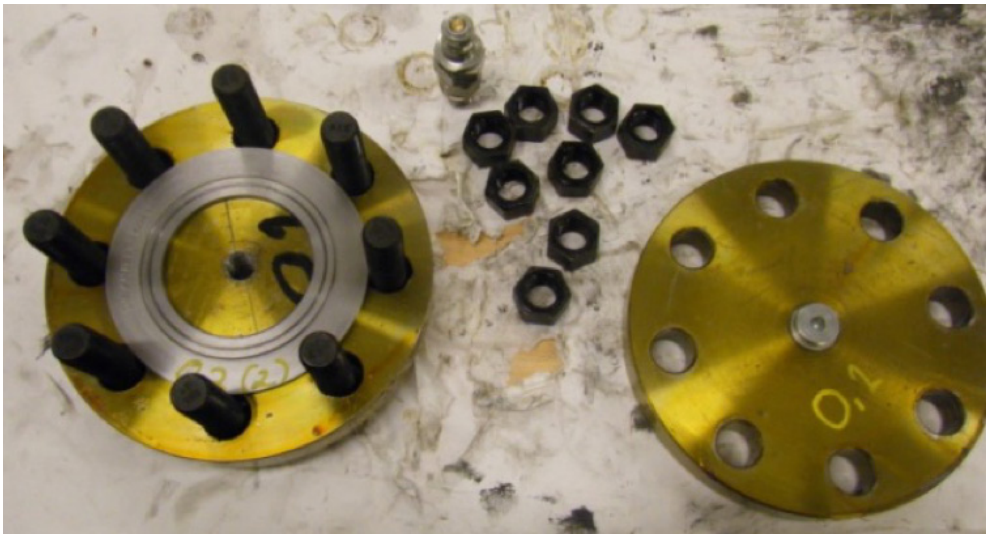


Figure 11. Assembly of test specimen

Figure 12. Helium testing – 5 barg

Figure 13. Helium testing – 5 barg

Figure 14. Helium testing – 5 barg

Figure 15. Water testing – 78 barg

Pictures from testing of DeltaV-Seal with use of 0,3 mm damage

Figure 16. Helium testing – 5 barg

Figure 17. Helium testing – 5 barg - Leakage up to 95 Nm torque

Figure 18. Helium testing – 5 barg – No detected leakage at 108 Nm torque

Figure 19. Water testing – 78 barg

Figure 20. Water testing – 78 barg